MODIFIED CSMA/CA MAC STRATEGY FOR IOT ENABLE INTRA-VEHICULAR WIRELESS COMMUNICATION SYSTEMS

MD JAHAN ALI

Master of Science

UNIVERSITI MALAYSIA PAHANG

SUPERVISOR’S DECLARATION

I hereby declare that I have checked this thesis and in my opinion, this thesis is adequate in terms of scope and quality for the award of the degree of Master of Science.

____

(Supervisor’s Signature)

Full Name : DR. MD ARAFATUR RAHMAN

Position : SENIOR LECTURER

Date :

STUDENT'S DECLARATION

I hereby declare that the work in this thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at Universiti Malaysia Pahang or any other institutions.

____

(Student's Signature)

Full Name : MD JAHAN ALI

ID Number : MCC15006

Date : NOVEMBER, 2018

MODIFIED CSMA/CA MAC STRATEGY FOR IOT ENABLE INTRA-VEHICULAR WIRELESS COMMUNICATION SYSTEMS

MD JAHAN ALI

Thesis submitted in fulfillment of the requirements
for the award of the degree of
Master of Science

Faculty of Computer Systems and Software Engineering

UNIVERSITI MALAYSIA PAHANG

NOVEMBER, 2018

ACKNOWLEDGEMENTS

I am grateful and would like to express my sincere gratitude to my supervisor Dr. Md. Arafatur Rahman for his emerging ideas, invaluable guidance, continuous encouragement and constant support in making this research possible. He has always impressed me with his outstanding professional conduct, his strong conviction for science, and his belief that a master program is only a start of a life-long learning experience. I appreciate his consistent support from the first day I applied to graduate program to these concluding moments. I am truly grateful for his progressive vision about my training in science, his tolerance of my naive mistakes, and his commitment to my future career. I would also like to thank Dr. Muhammad Nomani Kabir for his help to develop MATLAB coding for my numerical modeling. I also sincerely thanks for the time spent for proofreading and correcting my many mistakes.

My sincere thanks go to all my lab mates and members of the staff of the Cmputer Systems and Software Engineering faculty, UMP, who helped me in many ways and made my stay at UMP pleasant and unforgettable. Many special thanks go to members of SysNet Lab research group for their excellent co-operation, inspirations and supports during this study.

I acknowledge my sincere indebtedness and gratitude to my parents for their love, dream and sacrifice throughout my life. I also acknowledge the sincerity of my parents, who consistently encouraged me to carry on my higher studies in Malaysia. I cannot find the appropriate words that could properly describe my appreciation for their devotion, support and faith in my ability to attain my goals. Special thanks should be given to my committee members. I would like to acknowledge their comments and suggestions, which was crucial for the successful completion of this study.

ABSTRAK

Konsep *Internet of Things* atau *Internet* untuk segalanya *(IoT)* boleh digunakan di dalam komunikasi kenderaan berikutan peningkatan mendadak di dalam nod peranti pengeran kerana permintaan tinggi terhadap aplikasi perlindungan, keselamatan, keselesaan yang berbeza. Bagi menjalankan komunikasi di antara nod-nod di dalam kenderaan, rangkaian kawalan jaringan beserta seni bina sambungan wayar merupakan solusi yang utama. Walau bagaimanapun, solusi ini tidak berdaya maju dan keanjalan kerana seni bina yang kompleks di dalam sambungan wayar beserta permintaan pengesan yang tinggi di dalam kenderaan; menyebabkan seni bina sambungan wayar digantikan dengan tanpa wayar. Selain itu, boleh skala merupakan isu utama dalam pengenalan konsep *IoT* di dalam *Intra-Vehicular Wireless Sensor Networks* atau Rangkaian peranti pengeran tanpa wayar intra-kenderaan *(IVWSNs). IoT* membolehkan *Intra-Vehicular Wireless Sensor Networks (IoT-IVWSNs)* yang merujuk kepada rangkaian di mana sejumlah besar peranti pengeran berhubung antara satu sama lain untuk berkongsi maklumat status kenderaan dalam membangunkan sistem kenderaan pintar. Bilangan nod peranti pengeran di dalam kenderaan telah meningkat secara mendadak berikutan dari peningkatan penggunaan kenderaan. Fenomena kesesakan lalu lintas menimbulkan masalah di dalam *IVWSNs* di mana bebanan lalu lintas serta bilangan peranti pengeran meningkat. Masalah ini dapat diselesaikan dengan mengurangkan had protokol *Media Access Control* atau Kawalan akses media *(MAC)* yang sedia ada. Dalam kajian ini, pertama sekali, adalah menyelidik prestasi rangkaian di dalam *IoT-IVWSNs* dengan protokol sedia ada dengan mempertimbangkan pelbagai parameter rangkaian yang dioptimumkan serta menentukan batasan-batasannya. Tambahan itu, kajian ini akan membincangkan reka bentuk senario IVWSN, komponen rangkaian, teknologi tanpa wayar yang sesuai dan parameter dalam menilai prestasi dan kebolehpercayaan rangkaian dengan cara yang berskala. Kedua, strategi *History Based CSMA/CA MAC* dicadangkan untuk mempertingkatkan lagi prestasi rangkaian dengan mengurangkan batasan di dalam persekitaran *IoT-IVWSNs*. Akhir sekali, prestasi rangkaian diuji melalui simulasi diskret berangka bagi menunjukkan dapatan berkesan yang diperolehi. Dapatan yang dihasilkan menunjukkan bahawa prestasi rangkaian meningkat 75% dari segi metrik prestasi rangkaian kelewatan hujung-ke-hujung.

ABSTRACT

The concept of the Internet of Things (IoT) can be utilized in vehicular communication since the number of sensor nodes is raising tremendously because of the uplifting demand of different secure, safety and convenience applications. In order to do the communication among these nodes inside the vehicle, controller area network with wired architecture provides a prominent solution. However, this solution will not be viable and flexible because of the architectural complexity of wire connections in the demand of a large number of sensors inside the vehicle; hence the wired architectures are replaced by wireless ones. Moreover, scalability will be an important issue while introducing the IoT concept in Intra-Vehicular Wireless Sensor Networks (IVWSNs). The IoT enabled Intra-Vehicular Wireless Sensor Networks (IoT-IVWSNs) refer to the network where a large number of sensors are connected with each other for sharing the vehicle’s status information to develop a smart vehicular system. The number of sensor nodes in the vehicle has increased significantly due to the increasing vehicular applications. The phenomenon of congestion poses a problem in the IVWSNs where the traffic load and the number of sensors are increased. These problems can be resolved by mitigating the limitation of the existing Media Access Control (MAC) protocols. In this study firstly, it is investigated the network performance in IoT-IVWSNs with existing protocol by considering different optimized network parameters and defines the limitations. Moreover, it discusses the design of IVWSN scenario, network components, suitable wireless technology and parameters for evaluating the performance and network reliability in a scalable fashion. Secondly, a History-Based CSMA/CA MAC strategy is proposed to minimize the end to end of the network. The developed new MAC improves the network performance by reducing the limitations in the IoT-IVWSNs environment. Finally, the performance has been tested through discrete numerical simulation to show the result effectively. The results show that the network performance is increased 75% approximately in term of network performance metrics end-to-end delay.

TABLE OF CONTENT

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

dBm	Decibel-milliwatts
d	Distance
P_L	Path loss
P_t	Transmit power
P_r	Receiver power
C_f	Carrier frequency
Rs	Receiver sensitivity
$X\sigma$	Gaussian random variable
σ	Shadowing deviation
γ	Path loss exponent

LIST OF ABBREVIATIONS

BE	Backoff Exponent
BEB	Binary Exponent Backoff
CAN	Controller Area Network
CAP	Contention Access Period
CCA	Clear Channel Assessments
CEF	Contention-Free Period
CSMA/CA	Carrier Sense Multiple Access-Collision Avoidance
CU	Control Unit
ECU	Electronic Control Unit
ED	End Device
FFD	Full Function Device
GST	Guaranteed Time Slot
IoT	Internet of Things
ITS	Intelligent Transportation System
IVWSNs	Intra-Vehicle Wireless Sensor Networks
IoT-IVWSN	IoT enabled Intra-Vehicle Wireless Sensor Networks
IVS	Intelligent Vehicular System
NB	Number of Backoff Stages
MAC	Medium Access Protocol
PAN	Personal Area Network
PHY	Physical
PU	Processing Unit
RFD	Reduced Function Device
RFID	Radio Frequency Identifier
SBE	Saved BE
SNB	Saved NB
UWB	Ultra-wideband
VANETs	Vehicular Ad-hoc Networks
V2V	Vehicle-to-Vehicle
V2I	Vehicle-to-Infrastructure
WSNs	Wireless Sensor Networks

REFERENCES

Abdmeziem, M. R., Tandjaoui, D., & Romdhani, I. (2016). Architecting the internet of things: state of the art *Robots and Sensor Clouds* (pp. 55-75).

Ahmed, M., Saraydar, C. U., ElBatt, T., Yin, J., Talty, T., & Ames, M. (2007a). Intra-vehicular wireless networks. Paper presented on IEEE Globecom Workshops.

Ahmed, M., Saraydar, C. U., ElBatt, T., Yin, J., Talty, T., & Ames, M. (2007b). Intra-vehicular wireless networks. Paper presented on IEEE Globecom Workshops.

Akyildiz, I. F., & Vuran, M. C. (2010). Wireless Sensor Networks (Vol. 4): John Wiley & Sons.

Al-Fuqaha, A., Guizani, M., Mohammadi, M., Aledhari, M., & Ayyash, M. (2015). Internet of things: a survey on enabling technologies, protocols, and applications. *IEEE Communications Surveys & Tutorials, 17*(4), 2347-2376.

Al-Jemeli, M., & Hussin, F. A. (2015). An energy efficient cross-layer network operation model for IEEE 802.15. 4-based mobile wireless sensor networks. *IEEE Sensors Journal, 15*(2), 684-692.

Alvi, A. N., Naqvi, S. S., Bouk, S. H., Javaid, N., Qasim, U., & Khan, Z. A. (2012). Evaluation of slotted CSMA/CA of IEEE 802.15. 4. Paper presented at the 7th International Conference on Broadband, Wireless Computing, Communication and Applications (BWCCA).

An, S.-h., Lee, B.-H., & Shin, D.-R. (2011). A survey of intelligent transportation systems. Paper presented at the 3rd International Conference on Computational Intelligence, Communication Systems and Networks (CICSyN).

Anastasi, G., Conti, M., & Di Francesco, M. (2011). A comprehensive analysis of the MAC unreliability problem in IEEE 802.15. 4 wireless sensor networks. *IEEE Transactions on Industrial Informatics, 7*(1), 52-65.

Anchora, L., Capone, A., Mighali, V., Patrono, L., & Simone, F. (2014). A novel MAC scheduler to minimize the energy consumption in a wireless sensor network. *Ad Hoc Networks*, *16*, 88-104.

Anusha, M., Vemuru, S., & Gunasekhar, T. (2015). TDMA-based MAC protocols for scheduling channel allocation in multi-channel wireless mesh networks using cognitive radio. Paper presented at the International Conference on Circuit, Power and Computing Technologies (ICCPCT).

Aziz, S. M., & Pham, D. M. (2013). Energy efficient image transmission in wireless multimedia sensor networks. *IEEE Communications Letters, 17*(6), 1084-1087.

Bas, C. U., & Ergen, S. C. (2012). Ultra-wideband channel model for intra-vehicular wireless sensor networks. Paper presented at the IEEE Wireless Communications and Networking Conference (WCNC).

Bas, C. U., & Ergen, S. C. (2013). Ultra-wideband channel model for intra-vehicular wireless sensor networks beneath the chassis: from statistical model to simulations. *IEEE Transactions on Vehicular Technology, 62*(1), 14-25.

Bello, O., & Zeadally, S. (2016). Intelligent device-to-device communication in the internet of things. *IEEE Systems Journal, 10*(3), 1172-1182.

Bhargav, K. K., & Singhal, R. (2013). Zigbee based VANETs for accident rescue missions in 3G WCDMA networks. Paper presented at the Global Humanitarian Technology Conference (GHTC).

Bhosale, V., & Ladhe, S. (2018). Survey on beacon-enabled IEEE 802.15.4 MAC mechanisms. *International Journal of Applied Engineering Research, 13*(6), 3725-3737.

Biswas, S. (2017). Simulation model of beacon enabled 802.15.4 networks with OPNET modeler. Paper presented at the IEEE Electrical Engineering Congress (EECON).

Blumenstein, J., Mikulasek, T., Prokes, A., Zemen, T., & Mecklenbrauker, C. (2015). Intra-vehicular path loss comparison of uwb channel for 3-11 GHz and 55-65 GHz. Paper presented at the IEEE International Conference on Ubiquitous Wireless Broadband (ICUWB).

Brienza, S., De Guglielmo, D., Anastasi, G., Conti, M., & Neri, V. (2013). *S*trategies for optimal MAC parameter setting in IEEE 802.15. 4 wireless sensor networks: A performance comparison. Paper presented at the IEEE Symposium on Computers and Communications (ISCC).

Brienza, S., Roveri, M., Guglielmo, D. D., & Anastasi, G. (2016). Just-in-time adaptive algorithm for optimal parameter setting in 802.15.4 WSNs. *ACM Transactions on Autonomous and Adaptive Systems (TAAS), 10*(4), 27.

Bronzi, W., Frank, R., Castignani, G., & Engel, T. (2014). Bluetooth low energy for inter-vehicular communications. Paper presented at the IEEE Vehicular Networking Conference (VNC).

Buratti, C. (2010). Performance analysis of IEEE 802.15. 4 beacon-enabled mode. *IEEE Transactions on Vehicular Technology, 59*(4), 2031-2045.

Chen, K.-C., & Lien, S.-Y. (2014). Machine-to-machine communications: technologies and challenges. *Ad Hoc Networks, 18*, 3-23.

Chen, S.-K., Kao, T., Chan, C.-T., Huang, C.-N., Chiang, C.-Y., Lai, C.-Y., Wang, P.-C. (2012). A reliable transmission protocol for zigbee-based wireless patient monitoring. *IEEE Transactions on Information Technology in Biomedicine, 16*(1), 6-16.

Chen, X., Ng, D. W. K., & Chen, H.-H. (2016). Secrecy wireless information and power transfer: challenges and opportunities. *IEEE Wireless Communications, 23*(2), 54-61.

Collotta, M., Scatà, G., & Pau, G. (2013). A priority-based CSMA/CA mechanism to support deadline-aware scheduling in home automation applications using IEEE 802.15.4. *International Journal of Distributed Sensor Networks, 9*(5), 139804.

Conti, M., Dehghantanha, A., Franke, K., & Watson, S. (2018). Internet of things security and forensics: challenges and opportunities. *Future Generation Computer Systems, 78,* 544-546.

Coronato, A., De Pietro, G., Park, J.-H., & Chao, H.-C. (2010). A framework for engineering pervasive applications applied to intra-vehicular sensor network applications. *Mobile Networks and Applications, 15*(1), 137-147.

Cuomo, F., Abbagnale, A., & Cipollone, E. (2013). Cross-layer network formation for energy-efficient IEEE 802.15.4/zigbee wireless sensor networks. *Ad Hoc Networks, 11*(2), 672-686.

Di Francesco, M., Anastasi, G., Conti, M., Das, S. K., & Neri, V. (2011). Reliability and energy-efficiency in IEEE 802.15. 4/zigbee sensor networks: an adaptive and cross-layer approach. *IEEE Journal on Selected Areas in Communications, 29*(8), 1508-1524.

Faezipour, M., Nourani, M., Saeed, A., & Addepalli, S. (2012). Progress and challenges in intelligent vehicle area networks. *Communications of the ACM, 55*(2), 90-100.

Ferdous, R. M., Reza, A. W., & Siddiqui, M. F. (2016). Renewable energy harvesting for wireless sensors using passive RFID tag technology: a review. *Renewable and Sustainable Energy Reviews, 58,* 1114-1128.

Ganesh, S., & Amutha, R. (2013). Efficient and secure routing protocol for wireless sensor networks through SNR based dynamic clustering mechanisms. *Journal of Communications and Networks, 15*(4), 422-429.

Gao, M., Wang, P., Wang, Y., & Yao, L. (2018). Self-powered zigbee wireless sensor nodes for railway condition monitoring. *IEEE Transactions on Intelligent Transportation Systems, 19*(3), 900-909.

Gubbi, J., Buyya, R., Marusic, S., & Palaniswami, M. (2013). Internet of things (IoT): a vision, architectural elements, and future directions. *Future Generation Computer Systems, 29*(7), 1645-1660.

Hamid, Z., & Hussain, F. B. (2014). QoS in wireless multimedia sensor networks: a layered and cross-layered approach. *Wireless Personal Communications, 75*(1), 729-757.

Han, B., Cao, X., Shi, H., & Wang, L. (2018). An analytical model for IEEE 802.15. 4 wireless networks with periodic traffic under interference. Paper presented at the 33rd Youth Academic Annual Conference of Chinese Association of Automation (YAC).

Han, D.-M., & Lim, J.-H. (2010). Smart home energy management system using IEEE 802.15. 4 and zigbee. *IEEE Transactions on Consumer Electronics, 56*(3), 1403-1410.

Hartenstein, H., & Laberteaux, K. (2010). VANET: vehicular applications and inter-networking technologies (Vol. 1): Wiley Online Library.

Hasbollah, A. A., Ariffin, S. H., & Hamini, M. I. A. (2009). Performance analysis for 6loWPAN IEEE 802.15.4 with IPv6 network. Paper presented at the IEEE Region 10 Conference (TENCON).

Hashemi, M., Si, W., Laifenfeld, M., Starobinski, D., & Trachtenberg, A. (2013). Intra-car wireless sensors data collection: a multi-hop approach. Paper presented at the Vehicular Technology Conference (VTC).

Huang, P., Xiao, L., Soltani, S., Mutka, M. W., & Xi, N. (2013). The evolution of MAC protocols in wireless sensor networks: a survey. *IEEE Communications Surveys & Tutorials, 15*(1), 101-120.

Huang, T.-Y., Chang, C.-J., Lin, C.-W., Roy, S., & Ho, T.-Y. (2015a). Intra-vehicle network routing algorithm for wiring weight and wireless transmit power minimization. Paper presented at the IEEE 20th Asia and South Pacific Design Automation Conference (ASPDAC).

Hwang, S., & Yu, D. (2012). Remote monitoring and controlling system based on zigbee networks. *International Journal of Software Engineering and Its Applications, 6*(3), 35-42.

Iova, O., Picco, G. P., Istomin, T., & Kiraly, C. (2016). RPL, the routing standard for the internet of things... Or Is It? *IEEE Communications Magazine*, *54(12),* 16-22.

Iturri, P. L., Aguirre, E., Azpilicueta, L., Garate, U., & Falcone, F. (2014). Zigbee radio channel analysis in a complex vehicular environment. *IEEE Antennas and Propagation Magazine, 56*(4), 232-245.

Jabeen, Q., Khan, F., Khan, S., & Jan, M. A. (2016). Performance improvement in multihop wireless mobile adhoc networks. *the Journal Applied, Environmental, and Biological Sciences (JAEBS), 6*, 82-92.

Jawhar, I., Mohamed, N., & Zhang, L. (2010). Inter-vehicular communication systems, protocols and middleware. Paper presented at the IEEE 5th International Conference on Networking, Architecture, and Storage (NAS).

Jin, Y., Kim, K. J., & Kwak, K. S. (2011). Performance analysis of UWB intra-vehicle transmitted-reference communication systems. Paper presented at the IEEE Consumer Communications and Networking Conference (CCNC).

Jin, Y., Kwak, D., & Kwak, K. S. (2012). Performance analysis of intra-vehicle ultra-wide band propagation in multi-user environments. Paper presented at the IEEE 1st International Workshop on Vehicular Communications, Sensing, and Computing (VCSC).

Jung, K.-H., Lee, H.-R., Lim, W.-S., & Suh, Y.-J. (2014). An adaptive collision resolution scheme for energy efficient communication in IEEE 802.15. 4 networks. *Computer Networks, 58*, 39-57.

Jurčík, P., & Koubâa, A. (2007). The IEEE 802.15. 4 OPNET simulation model: reference guide v2. 0. *IPP-HURRAY Technical Report, HURRAY-TR-070509*.

Kandhalu, A., Xhafa, A., & Hosur, S. (2013). Towards bounded-latency bluetooth low energy for in-vehicle network cable replacement. Paper presented at the International Conference on Connected Vehicles and Expo (ICCVE).

Khaleel, H. R., Al-Rizzo, H. M., & Rucker, D. G. (2012). Compact polyimide-based antennas for flexible displays. *Journal of Display Technology, 8*(2), 91-97.

Khanafer, M., Guennoun, M., & Mouftah, H. T. (2014). A survey of beacon-enabled IEEE 802.15.4 MAC protocols in wireless sensor networks. *IEEE Communications Surveys & Tutorials, 16*(2), 856-876.

Khanapurkar, M., Bajaj, P., & Gharode, D. (2008). A design approach for intelligent vehicle black box system with intra-vehicular communication using lin/flex-ray protocols. Paper presented at the IEEE International Conference on Industrial Technology (ICIT).

Khuandaga, G., Iqbal, A., & Kwak, K. S. (2011). Performance analysis of modulation schemes in intra vehicle communications (IVC) channel. Paper presented at the 13th International Conference on Advanced Communication Technology (ICACT).

Koubaa, A., Alves, M., & Tovar, E. (2006). A comprehensive simulation study of slotted CSMA/CA for IEEE 802.15.4 wireless sensor networks. Paper presented at the IEEE International Workshop on Factory Communication Systems.

Lee, D., & Chung, K. (2010). Adaptive duty-cycle based congestion control for home automation networks. *IEEE Transactions on Consumer Electronics, 56*(1), 42-47.

Lee, S.-Y., Shin, Y.-S., Lee, K.-W., & Ahn, J.-S. (2014). Performance analysis of extended non-overlapping binary exponential backoff algorithm over IEEE 802.15.4. *Telecommunication Systems*, *55*(1), 39-46.

Li, S., Da Xu, L., & Zhao, S. (2015). The internet of things: a survey. *Information Systems Frontiers, 17*(2), 243-259.

Li, W., Hu, X. Y., & Jiang, T. (2018). Path loss models for IEEE 802.15.4 vehicle-to-infrastructure communications in rural areas. *IEEE Internet of Things Journal, 5(5)*,3865-3875.

Li, X., Niu, J., Kumari, S., Wu, F., Sangaiah, A. K., & Choo, K.-K. R. (2018). A three-factor anonymous authentication scheme for wireless sensor networks in internet of things environments. *Journal of Network and Computer Applications, 103*, 194-204.

Lin, J.-R., Talty, T., & Tonguz, O. K. (2013). An empirical performance study of intra-vehicular wireless sensor networks under wifi and bluetooth interference. Paper presented at the IEEE Global Communications Conference (GLOBECOM).

Lin, J.-R., Talty, T., & Tonguz, O. K. (2015a). A blind zone alert system based on intra-vehicular wireless sensor networks. *IEEE Transactions on Industrial Informatics*, *11*(2), 476-484.

Lin, J.-R., Talty, T., & Tonguz, O. K. (2015b). On the potential of bluetooth low energy technology for vehicular applications. *IEEE Communications Magazine*, *53*(1), 267-275.

Liu, R., Herbert, S., Loh, T. H., & Wassell, I. J. (2011). A study on frequency diversity for intra-vehicular wireless sensor networks (wsns). Paper presented at the Vehicular Technology Conference (VTC).

Lu, N., Cheng, N., Zhang, N., Shen, X., & Mark, J. W. (2014). Connected vehicles: solutions and challenges. *IEEE Internet of Things Journal, 1*(4), 289-299.

Mamdouhi, H., Khatun, S., & Ahmadi, K. (2009). An intra wireless communication and remote control mechanism in vehicular ad-hoc network. Paper presented at the 3rd Uksim European Symposium on Computer Modeling and Simulation (EMS).

Mandal, K., Sen, A., Chakraborty, A., Roy, S., Batabyal, S., & Bandyopadhyay, S. (2011). Road traffic congestion monitoring and measurement using active RFID and GSM technology. Paper presented at the 14th International IEEE Conference on Intelligent Transportation Systems (ITSC).

McClellan, S., Follmer, T., Maynard, E., Capps, E., Larson, G., Ord, D., Vo, V. (2014). System and method for monitoring vehicle parameters and driver behavior: Google Patents.

Minooei, H., & Nojumi, H. (2007). Performance evaluation of a new backoff method for IEEE 802.11. *Computer Communications, 30*(18), 3698-3704.

Mourad, A., Heigl, F., & Hoeher, P. A. (2016). Performance evaluation of concurrent IEEE 802.11 systems in the automotive domain. Paper presented at the IEEE 41st Conference on Local Computer Networks (LCN).

Nguyen, D. T., Singh, J., Le, H. P., & Soh, B. (2009). A hybrid TDMA protocol based ultra-wide band for in-car wireless communication. Paper presented at the IEEE Region 10 Conference (TENCON).

Palattella, M., Faridi, A., Boggia, G., Camarda, P., Grieco, L., Dohler, M., & Lozano, A. (2014). Performance analysis of the IEEE 802.15. 4 MAC layer. *ZigBee Networks, Protocols and Applications*.

Pantazis, N. A., Nikolidakis, S. A., & Vergados, D. D. (2013). Energy-efficient routing protocols in wireless sensor networks: a survey. *IEEE Communications Surveys & Tutorials, 15*(2), 551-591.

Park, P., Di Marco, P., Fischione, C., & Johansson, K. H. (2013). Modeling and optimization of the IEEE 802.15.4 protocol for reliable and timely communications. *IEEE Transactions on Parallel and Distributed Systems, 24*(3), 550-564.

Park, P., Fischione, C., & Johansson, K. H. (2011). Adaptive IEEE 802.15.4 medium access control protocol for control and monitoring applications *Wireless Networking Based Control* 271-300.

Park, P., Fischione, C., & Johansson, K. H. (2013). Modeling and stability analysis of hybrid multiple access in the IEEE 802.15.4 protocol. *ACM Transactions on Sensor Networks (TOSN), 9*(2), 13.

Parthasarathy, D., Whiton, R., Hagerskans, J., & Gustafsson, T. (2016). An in-vehicle wireless sensor network for heavy vehicles. Paper presented at the IEEE 21st International Conference on Emerging Technologies and Factory Automation (ETFA).

Peng, C., Qian, K., & Wang, C. (2015). Design and application of a VOC-monitoring system based on a zigBee wireless sensor network. *IEEE Sensors Journal, 15*(4), 2255-2268.

Pinelis, M. (2013). Automotive sensors and electronics: trends and developments in 2013. *Automotive Sensors and Electronics Expo, Detroit, MI, USA.*

Pollin, S., Ergen, M., Ergen, S. C., Bougard, B., Van der Perre, L., Moerman, I., Catthoor, F. (2008). Performance analysis of slotted carrier sense IEEE 802.15. 4 medium access layer. *IEEE Transactions on Wireless Communications, 7(9),* 3359-3371.

Qu, F., Li, J., Yang, L., & Talty, T. (2011). Measured channel capacity of SIMO-UWB for intra-vehicle communications. Paper presented at the 5th European Conference on Antennas and Propagation (EUCAP).

Qu, F., Wang, F.-Y., & Yang, L. (2010a). Intelligent transportation spaces: vehicles, traffic, communications, and beyond. *IEEE Communications Magazine, 48*(11), 136-142.

Qu, F., Wang, F.-Y., & Yang, L. (2010b). Intelligent transportation spaces: vehicles, traffic, communications, and beyond. *IEEE Communications Magazine*, *48*(11), 136-142.

Rahman, M. A. (2014a). Design of wireless sensor network for intra-vehicular communications. Paper presented at the International Conference on Wired/Wireless Internet Communications.

Rahman, M. A. (2014b). Reliability analysis of zigbee based intra-vehicle wireless sensor networks. Paper presented at the International Workshop on Communication Technologies for Vehicles.

Rahman, M. A., Ali, J., Kabir, M. N., & Azad, S. (2017). A performance investigation on IoT enabled intra-vehicular wireless sensor networks. *International Journal of Automotive and Mechanical Engineering*, *14*, 3970-3984.

Rahman, M. A., Kabir, M. N., Azad, S., & Ali, J. (2015). On mitigating hop-to-hop congestion problem in IoT enabled intra-vehicular communication. Paper presented at the 4th International Conference on Software Engineering and Computer Systems (ICSECS).

Ramya, C. M., Shanmugaraj, M., & Prabakaran, R. (2011). Study on zigbee technology. Paper presented at the 3rd International Conference on Electronics Computer Technology (ICECT).

Ranjit, J. S., & Shin, S. (2013). A modified IEEE 802.15.4 superframe structure for guaranteed emergency handling in wireless body area network. *Network Protocols and Algorithms, 5*(2), 1-15.

Rao, V., & Marandin, D. (2006). Adaptive backoff exponent algorithm for zigbee (IEEE 802.15.4). Paper presented at the International Conference on Next Generation Teletraffic and Wired/Wireless Advanced Networking.

Rasheed, M. B., Javaid, N., Haider, A., Qasim, U., Khan, Z. A., & Alghamdi, T. A. (2014). An energy consumption analysis of beacon enabled slotted CSMA/CA IEEE 802.15. 4. Paper presented at the 28th International Conference on Advanced Information Networking and Applications Workshops (WAINA).

Rasouli, H., Kavian, Y. S., & Rashvand, H. F. (2014). ADCA: Adaptive duty cycle algorithm for energy efficient IEEE 802.15.4 beacon-enabled wireless sensor networks. *IEEE Sensors Journal, 14*(11), 3893-3902.

Rault, T., Bouabdallah, A., & Challal, Y. (2014). Energy efficiency in wireless sensor networks: a top-down survey. *Computer Networks, 67*, 104-122.

Rawat, P., Singh, K. D., & Bonnin, J. M. (2016). Cognitive radio for M2M and internet of things: a survey. *Computer Communications, 94*, 1-29.

Rawat, P., Singh, K. D., Chaouchi, H., & Bonnin, J. M. (2014). Wireless sensor networks: a survey on recent developments and potential synergies. *The Journal of Supercomputing, 68*(1), 1-48.

Ross, N., & Schuhmacher, D. (2017). Wireless network signals with moderately correlated shadowing still appear poisson. *IEEE Transactions on Information Theory*, *63*(2), 1177-1198.

Sadi, Y., & Ergen, S. C. (2013). Optimal power control, rate adaptation, and scheduling for UWB-based intravehicular wireless sensor networks. *IEEE Transactions on Vehicular Technology, 62*(1), 219-234.

Shen, W., Zhang, T., Barac, F., & Gidlund, M. (2014). PriorityMAC: A priority-enhanced MAC protocol for critical traffic in industrial wireless sensor and actuator networks. *IEEE Transactions on Industrial Informatics, 10*(1), 824-835.

Sheng, Z., Yang, S., Yu, Y., Vasilakos, A. V., McCann, J. A., & Leung, K. K. (2013). A survey on the ietf protocol suite for the internet of things: standards, challenges, and opportunities. *IEEE Wireless Communications, 20*(6), 91-98.

Shih, B.-Y., Chang, C.-J., Chen, A.-W., & Chen, C.-Y. (2010). Enhanced MAC channel selection to improve performance of IEEE 802.15. 4. *International Journal of Innovative Computing, Information and Control, 6*(12), 5511-5526.

Shih, B.-Y., Chen, C.-Y., Shih, C.-H., & Tseng, J.-Y. (2010). The development of enhancing mechanisms for improving the performance of IEEE 802.15. 4. *International Journal of Physical Sciences, 5*(6), 884-897.

Si, W., Starobinski, D., & Laifenfeld, M. (2018). A robust load balancing and routing protocol for intra-car hybrid wired/wireless networks. *IEEE Transactions on Mobile Computing, 42,* 1-16.

Singh, B., & Lobiyal, D. (2013). A MAC-layer retransmission technique for collided packets in wireless sensor network. *Wireless Personal Communications, 72*(4), 2499-2518.

Snigdh, I., & Gosain, D. (2016). Analysis of scalability for routing protocols in wireless sensor networks. *Optik-International Journal for Light and Electron Optics, 127*(5), 2535-2538.

Somani, N. A., & Patel, Y. (2012). Zigbee: A low power wireless technology for industrial applications. *International Journal of Control Theory and Computer Modelling (IJCTCM), 2*, 27-33.

Song, X., Li, X., Tang, W., & Zhang, W. (2016). A fusion strategy for reliable vehicle positioning utilizing RFID and in-vehicle sensors. *Information Fusion, 31*, 76-86.

Striccoli, D., Boggia, G., & Grieco, L. A. (2015). A markov model for characterizing IEEE 802.15.4 MAC layer in noisy environments. *IEEE Transactions on Industrial Electronics, 62*(8), 5133-5142.

Sun, Q.-b., Liu, J., Li, S., FAN, C.-x., & SUN, J.-j. (2010). Internet of things: summarize on concepts, architecture and key technology problem. *Journal of Beijing University of Posts and Telecommunications, 3*(3), 1-9.

Takayama, I., & Kajiwara, A. (2016). Intra-vehicle wireless harness with mesh-networking. Paper presented at the IEEE-APS Topical Conference on Antennas and Propagation in Wireless Communications (APWC).

Tavakoli, H., Mišić, J., Mišić, V. B., & Naderi, M. (2015). Energy-efficient cluster-head rotation in beacon-enabled IEEE 802.15.4 networks. *IEEE Transactions on Parallel and Distributed Systems, 26*(12), 3371-3380.

Tonguz, O., Tsai, H.-M., Saraydar, C., Talty, T., & Macdonald, A. (2007). Intra-car wireless sensor networks using RFID: opportunities and challenges. Paper presented at the IEEE Conference on Mobile Networking for Vehicular Environments.

Tonguz, O. K., Tsai, H.-M., Talty, T., Macdonald, A., & Saraydar, C. (2006). *RFID* technology for intra-car communications: a new paradigm. Paper presented at the IEEE Vehicular Technology Conference (VTC).

Toscano, E., & Bello, L. L. (2012). Comparative assessments of IEEE 802.15.4/zigbee and 6LoWPAN for low-power industrial WSNs in realistic scenarios. Paper presented at the IEEE 9th International Workshop on Factory Communication Systems (WFCS).

Tseng, H.-W., & Chuang, Y.-R. (2013). A cross-layer judgment scheme for solving retransmission problem in IEEE 802.15.4-based wireless body sensor networks. *IEEE Sensors Journal, 13*(8), 3124-3135.

Tuohy, S., Glavin, M., Hughes, C., Jones, E., Trivedi, M., & Kilmartin, L. (2015). Intra-vehicle networks: a review. *IEEE Transactions on Intelligent Transportation Systems, 16*(2), 534-545.

Tuohy, S., Glavin, M., Jones, E., Hughes, C., & Kilmartin, L. (2016). Hybrid testbed for simulating in-vehicle automotive networks. *Simulation Modelling Practice and Theory, 66*, 193-211.

Tuohy, S., Glavin, M., Jones, E., Trivedi, M., & Kilmartin, L. (2013). Next generation wired intra-vehicle networks, a review. Paper presented at the IEEE Conference on Intelligent Vehicles Symposium (IVS).

Uddin, M. F. (2016). Throughput analysis of a CSMA based WLAN with successive interference cancellation under rayleigh fading and shadowing. *Wireless Networks, 22*(4), 1285-1298.

Wadhwa, L., Deshpande, R. S., & Priye, V. (2016). Extended shortcut tree routing for zigbee based wireless sensor network. *Ad Hoc Networks, 37*, 295-300.

Wampler, D., Fu, H., & Zhu, Y. (2009). Security threats and countermeasures for intra-vehicle networks. Paper presented at the 5th International Conference on Information Assurance and Security.

Whitmore, A., Agarwal, A., & Da Xu, L. (2015). The internet of things: a survey of topics and trends. *Information Systems Frontiers, 17*(2), 261-274.

Xia, M., & Song, D. (2017). Application of wireless sensor network in smart buildings. Paper presented at the International Conference on Machine Learning and Intelligent Communications.

Yaala, S. B., & Bouallegue, R. (2016). On MAC layer protocols towards internet of things: from IEEE 802. 15.4 to IEEE 802.15.4e. Paper presented at the 24th International Conference on Software, Telecommunications, and Computer Networks (SoftCOM).

Yang, K. (2014). Wireless sensor networks. *Principles, Design and Applications*.

Ye, W., Heidemann, J., & Estrin, D. (2004). Medium access control with coordinated adaptive sleeping for wireless sensor networks. *IEEE/ACM Transactions on networking, 12*(3), 493-506.

Yu, B., Xu, L., & Li, Y. (2012). Bluetooth low energy (BLE) based mobile electrocardiogram monitoring system. Paper presented at the International Conference on Information and Automation (ICIA).

Yue, H., Zhang, C., Pan, M., Fang, Y., & Chen, S. (2012). A time-efficient information collection protocol for large-scale RFID systems. Paper presented at the IEEE Proceedings INFOCOM.

Zhang, T., Antunes, H., & Aggarwal, S. (2014). Defending connected vehicles against malware: challenges and a solution framework. *IEEE Internet of Things Journal, 1*(1), 10-21.

Zhao, X., Zhang, W., Niu, W., Zhang, Y., & Zhao, L. (2010). Power and bandwidth efficiency of IEEE 802.15.4 wireless sensor networks. Paper presented at the International Conference on Ubiquitous Intelligence and Computing.

Zhou, B., Cao, J., Zeng, X., & Wu, H. (2010). Adaptive traffic light control in wireless sensor network-based intelligent transportation system. Paper presented at the 72nd IEEE Vehicular Technology Conference (VTC).

Zhuo, S., Wang, Z., Song, Y.-Q., Wang, Z., & Almeida, L. (2013). iqueue-mac: A traffic adaptive duty-cycled mac protocol with dynamic slot allocation. Paper presented at the 10th Annual IEEE Communications Society Conference on Sensor, Mesh and Ad Hoc Communications and Networks (SECON).

Zulkifli, C., & Noor, N. (2017). Wireless sensor network and internet of things (IoT) solution in agriculture. *Pertanika Journal of Science & Technology, 25*(1), 91-100.